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FINAL REPORT ON TASK ORDER 1

EVALUATION OF THE PERFORMANCE OF TUNGSTEN - TUNGSTEN 26 RHENIUM THERMOCOUPLES TO ABOUT 5000°F

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA

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(NASA (Contract NAS8-5196)

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Southern Research Institute
Birmingham, Alabama
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SUMMARY

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This report concerns the evaluation and calibration to about 5000°F of tungsten-tungsten 26 rhenium thermocouples supplied by two manufacturers. The thermocouples were calibrated in a black body cavity in an inert atmosphere and the output of the couples versus temperature compared to the calibrations supplied by the manufacturers. For the Fenwal couple, the calibrations here provided a higher output suggesting that their calibration did not provide sufficient immersion in an isothermal zone if they used a 32°F reference. For the PDL couple the calibration curve obtained here was shifted but essentially parallel to the one provided by the manufacturer suggesting that their cavity was not black or that temperature measurements were made in a way that the emittance was unknown and assumed unity when actually lower. The immersion depth here should have been sufficient. Repeated runs were made to establish the repeatability and to obtain the relationship of millivolt output versus immersion depth. The output was less with shorter immersion depths up to about 4 diameters immersion.

After the calibration, the thermocouples were cycled to various temperatures up to about 4500°F in the atmosphere of an oxygen-acetylene burner. The couples were cycled a minimum of three times to each temperature to investigate the repeatability and reliability under these conditions. Generally, the repeatability and agreement with black body cavity calibrations were only fair with a variation between all thermocouples of about ± 7% over the temperature range. There was less variation for the smaller diameter Fenwal thermocouples.

AUTHOR

INTRODUCTION

This is the final report to the National Aeronautics and Space Administration covering the work performed under Task Order No. 1 of Contract No. NAS8-5196. The contract involves research, development and prototype model construction of calorimeter and thermocouple assemblies designed toward the Saturn and C-1 environment. This report deals with the evaluation of tungsten - tungsten 26 rhenium thermocouples supplied by Fenwal Corporation and Propulsion Development Laboratories, Incorporated.

DESCRIPTION OF THERMOCOUPLES

The thermocouples evaluated were composed of tungsten and tungsten 26 rhenium, with one material as the center wire and the other as a surrounding sealed cylinder. The outer cylinder was tungsten for the PDL couple and tungsten 26 rhenium for the Fenwal couple. The end of the cylinder and wire were welded together to form the junction. Both couples utilized beryllium oxide insulators between the wire and the cylinder.

The outside diameter of the Fenwal couple was uniform with the diameter of the cylinder being approximately $\frac{1}{8}$ inch O.D. and from 2 to $2\frac{1}{16}$ inches long. The lead wires of the Fenwal couple were shielded with a wrapped metal sheath (see Figure 14) and of the same composition as the junction materials. The outside diameter of the PDL couple was about $\frac{1}{4}$ inch, except at the junction where the diameter reduced to $\frac{1}{16}$ inch, with the overall lengths varying from $2\frac{3}{8}$ to $4\frac{9}{16}$ inches. The lead wires of this couple were not shielded and were made of materials other than those of the junction. One wire was copper.

As reported later, the ends of the leadwires were held in an ice bath as a reference during all calibrations. If the thermoelectric characteristics of the leadwires and their junctions were designed for balancing and opposing signals, this procedure was satisfactory; otherwise, some unknown potentials could have been developed in the thermocouple and its housing system. The precise information for an evaluation of this aspect was not provided. It appears that at least the Fenwal couple should have had no spurious emf's since the same compositions were used on the leadwire as in the junction.

BLACK BODY CAVITY CALIBRATION

Apparatus and Procedure

The tungsten - tungsten 26 rhenium thermocouples were calibrated in a black body cavity placed in an induction heating coil as shown in Figure 1. A tungsten cavity was used as the load for the induction coil with zirconia insulation to prevent contamination of the couples by foreign materials. The cavity was insulated with the zirconia grog to insure isothermal conditions and to protect the heating coil from the severe radiation. The leads from the thermocouple were both immersed in an ice bath at 32°F and the output read on a null balance potentiometer.

With the thermocouple in position in the cavity it was not possible to obtain optical temperature readings from down in the cavity. Therefore, a calibration of cavity temperature was made versus the temperature reading on the edge of the cavity. This calibration is shown in Figure 2. Observe that the deviation was a maximum of only about 10% at the top temperatures so an uncertainty in the calibration of 10% would still provide an absolute uncertainty in temperature of only about 1% which is the same as the readout of an optical pyrometer.

A reading during any run consisted of the following: power input to the induction furnace; time; temperature on the edge of the cavity; and millivolt output of the thermocouple at the 32°F reference temperature. Sufficient time was allowed between each reading for the output of the couple to reach steady state conditions. All optical temperature readings were made with a Leeds and Northrup type 8622 optical pyrometer. The millivolt outputs of the couples were read with a Leeds and Northrup type 8667 null balance potentiometer.

Data and Results

The final calibration curves for the Fenwal and PDL thermocouples are shown in Figures 3 and 4 and Tables 1 and 2, respectively. Note that our data and PDL's are in fair agreement; whereas our data and Fenwal's show considerable deviation. The reference temperature for the Fenwal data is not known.

Several runs were made on each couple to establish the variation of millivolt output with immersion depth. This variation is shown in Figures 5 and 6. The first runs were made using a tungsten cavity $\frac{9}{16}$ inch deep which allowed a penetration of about 2 diameters for the PDL couple and 4 diameters for the Fenwal couple. The final calibrations were made in a cavity which provided an immersion of $5\frac{1}{4}$ diameters and $10\frac{1}{2}$ diameters for the PDL and Fenwal couples, respectively. The duplicate data obtained at these deeper depths of immersion were in good agreement for the separate thermocouples.

About 4 diameters of immersion were required for the Fenwal couple and about 6 diameters for the PDL couple. The literature usually recommends a minimum of 5 to 10 diameters of immersion, depending upon the specific circumstances, to minimize the heat loss up the couple from the junction.

Both couples failed at temperatures well below 5000°F. The failure temperatures were 4450°F and 4610°F (2454°C and 2543°C), respectively, for the PDL and Fenwal couples. When the failures occurred the output voltage of the couples fell sharply to zero. Since beryllia melts at 4580°F (2526°C), this component may have induced the failures.

BURNER EXPOSURE CALIBRATION

Apparatus and Procedure

The apparatus used for the calibration runs in the burner exposures is shown in the schematic of Figure 7. The oxygen-acetylene burner has previously been found here to have a flame temperature between 4760°F and 4870°F, the melting points of molybdenum and zirconia, respectively, and a heat flux density of approximately 600 Btu/ft^2/sec.

A graphite sight tube was placed about $\frac{1}{16}$ inch over the tip of the couple to provide an approximate black body cavity for temperature readings with the optical pyrometer. The tube was positioned so that the contact surface with the thermocouple was a minimum to prevent conduction cooling to the cooler end of the tube. The tube also served to prevent the flame from optically obscuring the line of sight for the optical pyrometer during a run. A nitrogen purge was introduced around the couple immediately upon burner shut-off to prevent oxidation of the thermocouples during the cool down to room temperature.

During an exposure run the temperature of the couple was monitered with an optical pyrometer and is noted as observed temperature on the figures and in the tables. Since the cavity was essentially black body, no correction was made to the observed reading for emittance. The millivolt output of the couple versus time was recorded on an X-Y-time recorder. When the desired temperature was reached the burner was shut off and the observed optical temperature noted on the X-Y-time chart. Normally, the several exposures to any temperature were made consecutively so that any effects of the exposure could be observed on the run which followed. As for the other work, the output leads of the couples were immersed in a 32°F ice bath.

Data and Results

A typical plot taken from the X-Y-time recorder is shown in Figure 8. This plot gives the millivolt output versus time for a PDL thermocouple cycled to approximately 3850°F (2120°C). The observed temperature, obtained optically, is shown on the curve for each cycle. It is interesting to note that the observed temperature increased continuously from the first through the fourth cycles. However, this was not found to be necessarily true for other series of exposures. The data obtained during the cycles in the oxidizing atmosphere of the burner are presented in Tables 3 and 4 for the PDL and Fenwal couples, respectively.

Some comparative data for indicated and observed temperatures found for the PDL and Fenwal thermocouples are shown in Figures 9 and 10, respectively. These curves are a plot of the observed optical temperature versus the temperature obtained by the millivolt output of the thermocouples using the cavity type calibrations obtained here in the first part of the work. Perfect agreement with the cavity calibrations would be indicated if all points fell on the 45° reference line. The data for the PDL thermocouple (Figure 9) were in excellent agreement with the reference line at 2100°F (1149°C) but diverged by about 20% at about 3850°F (2121°C). The temperature indicated by the thermocouple millivolt output and the cavity calibration was higher than the observed temperature except during the first cycles at the lower temperature of about 2100°F (1149°C).

The comparative data for the Fenwal couple are shown in Figure 10. Although the over-all agreement of observed and calibrated temperatures was excellent, more scatter between individual cycles of the same series was found. The larger PDL couple may have permitted better heat reception from the burner with relatively less reradiation cooling from the downstream side so that more isothermal conditions were sustained around the periphery.

COMPARISON OF CAVITY AND BURNER RESULTS

Comparisons of the data obtained in the cavity and in the burner for the PDL and Fenwal couples are shown in Figures 11 and 12, respectively. The reference values from the manufacturer are included. Good agreement was obtained between the cavity calibration and the burner exposure on the Fenwal thermocouple above 2650°F. The manufacturer's values were quite divergent. Below 2650°F some deviation was found. The difference was a maximum of about 11% at 2100°F.

The calibrations here for the PDL couple were in good agreement at 2100°F but immediately began diverging. The greatest difference between the cavity calibration and the burner exposure was found to be about 18.5% at 4410°F. The data from the burner exposure and the manufacturer's values were in good agreement.

The composite plot of the exposure temperature of the junction versus the thermocouple output in millivolts for all runs both in the cavity and in the burner is shown in Figure 13. The reference values from the manufacturer are included. Even though the physical configurations of the thermocouples from Fenwal and PDL were different, the millivolt output for each should be the same for the cavity calibrations since the chemistry of the two metals (and presumedly the thermoelectric properties) was the same for each type. The physical configuration could influence the millivolt outputs in the burner exposures since the balance of heat pickup on the upstream side and reradiation from the downstream side could be different. From Figure 13, the PDL calibration and those here are in fair agreement within a band of about ± 7% over the full temperature range. The Fenwal reference temperature is not known so their calibration cannot be evaluated.

The cavity calibration and the burner exposure on the Fenwal couples provided very close agreement within 2% contrasted with the more divergent values of about 15% for the PDL couples when subjected to the two conditions.

The two thermocouples after exposure are shown in the picture of Figure 14. Both couples were heavily oxidized. It is conceivable that a low conductivity oxide was formed on the couples which interrupted the temperature gradient to the thermocouple junction allowing the outer surface (which was observed) to reach the desired temperature while the junction was at some lower temperature. Some errors in the readings were encountered due to the impossibility of allowing the couple to settle out completely at a particular temperature.

The third phase of this task order for the determination of the failure times at 5000°F was omitted since the thermocouples failed at about 4500°F during the initial calibrations.

CONCLUSIONS

The following conclusions may be drawn from the work performed under this task order:

1. An immersion depth of at least $4\frac{1}{2}$ diameters for the Fenwal couple and $5\frac{1}{4}$ diameters for the PDL couple is required to obtain reliable temperature readings.

2. The beryllia insulator in each of the couples should be replaced with some other material or eliminated to permit reliable performance to over 4500°F.

3. A reasonably reliable performance within ± 7% can be anticipated for these thermocouples up to about 4200°F.

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Approved:

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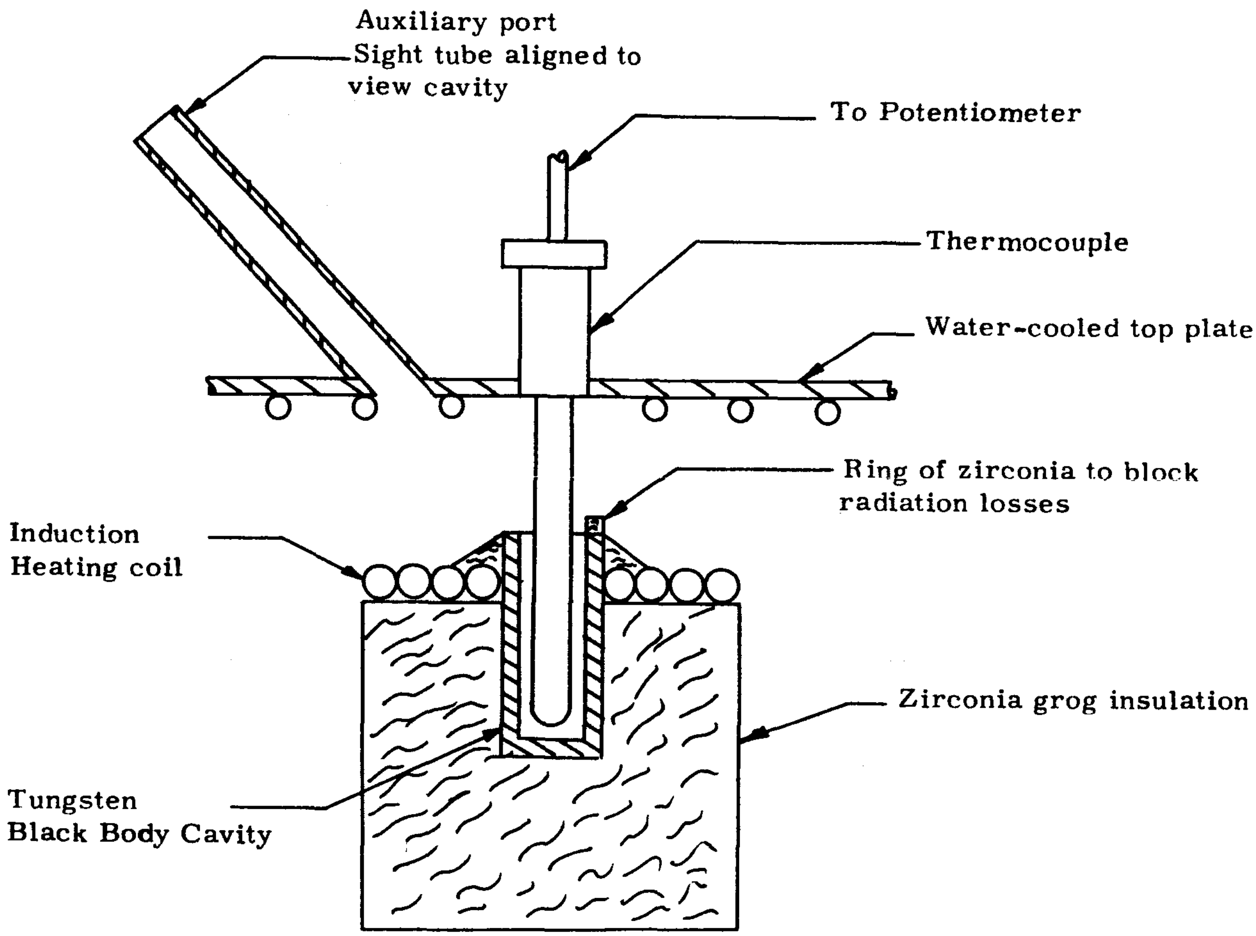

Figure 1. Cross Section Schematic of Apparatus Used to Evaluate High Temperature Thermocouples in A Black Body Cavity in an Inert Atmosphere

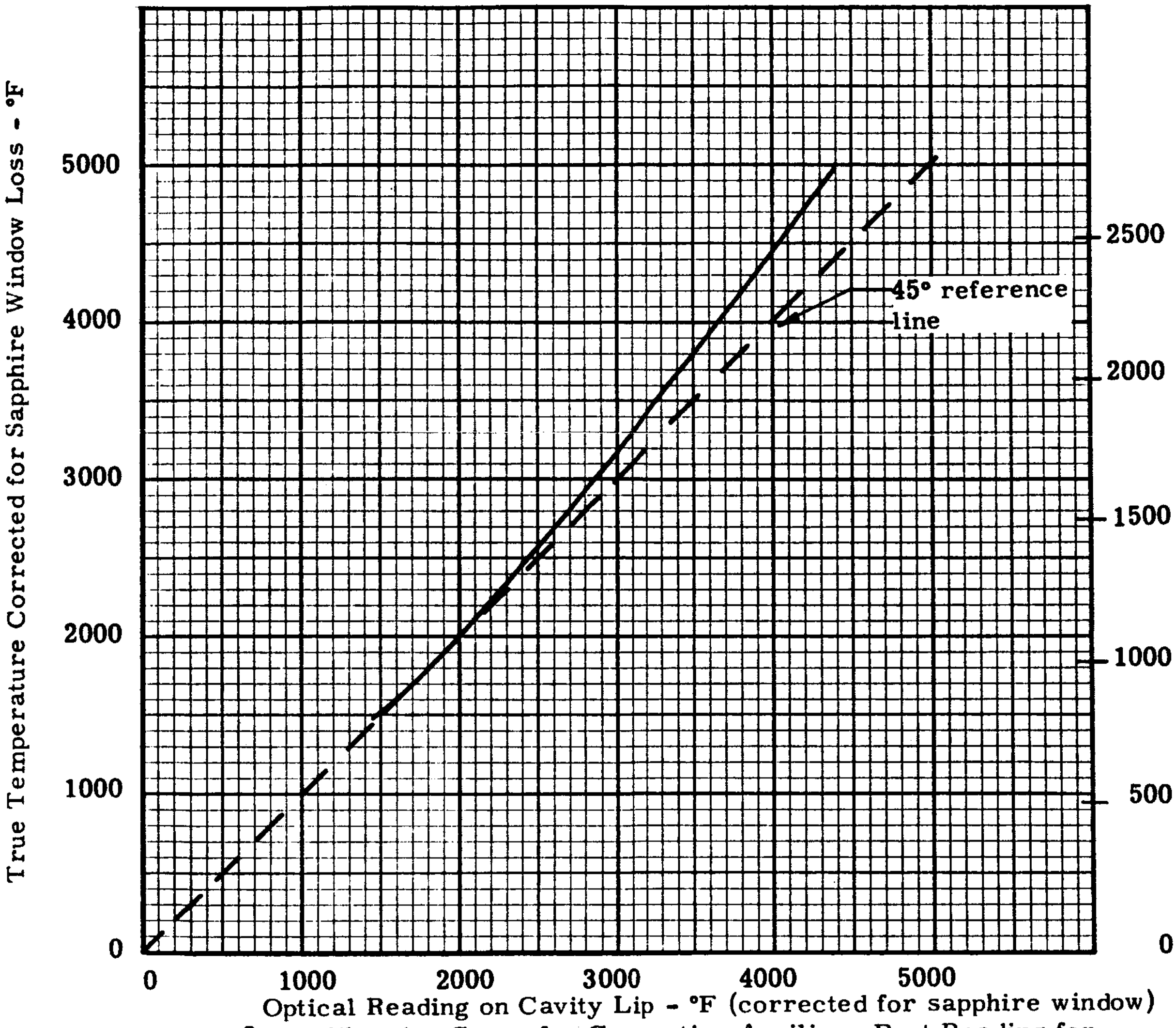

Figure 2. Calibration Curve for Converting Auxiliary Port Reading for True Temperature

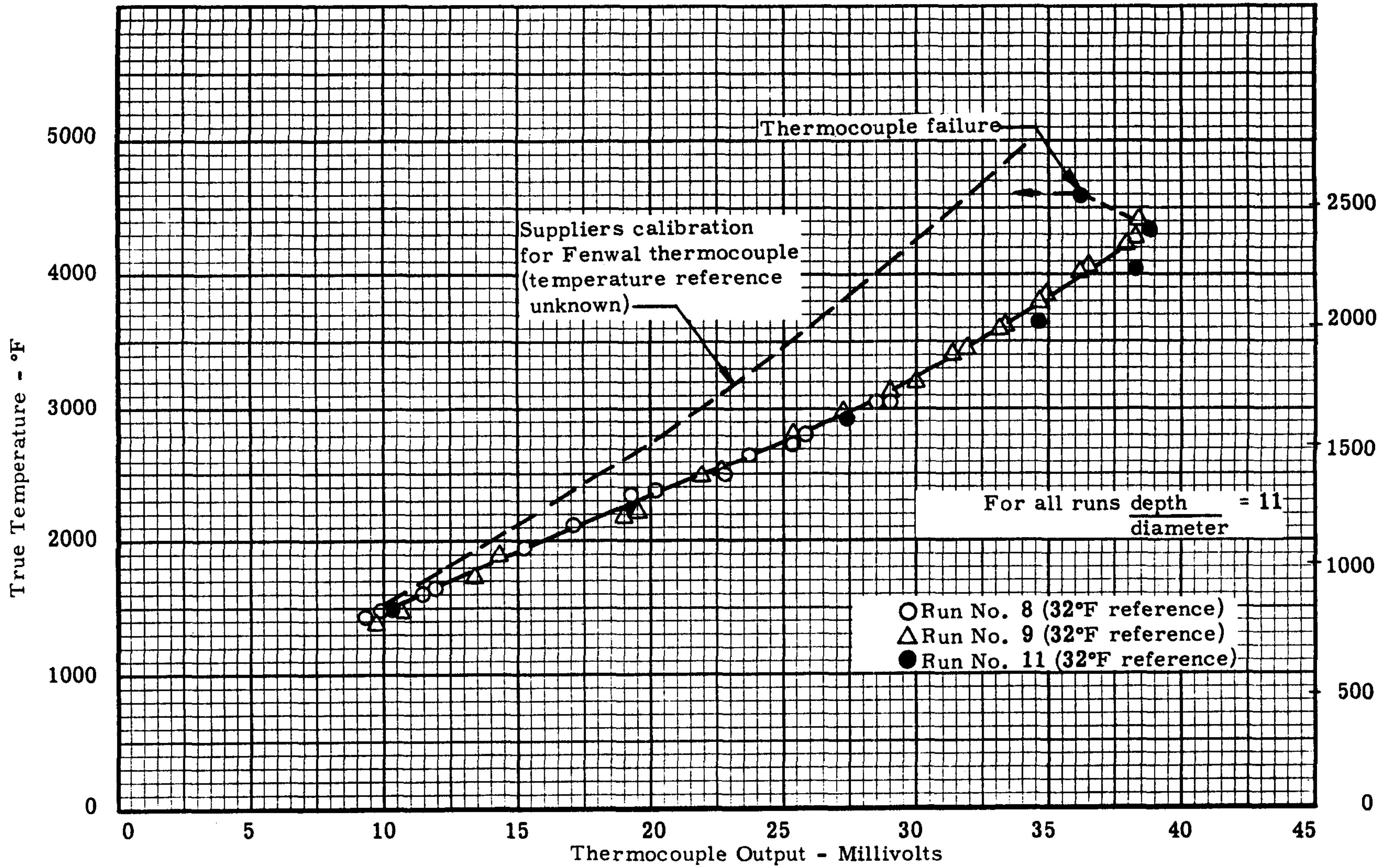

Figure 3. Final Calibration Curves for Fenwal Thermocouples Against Black Body Cavity

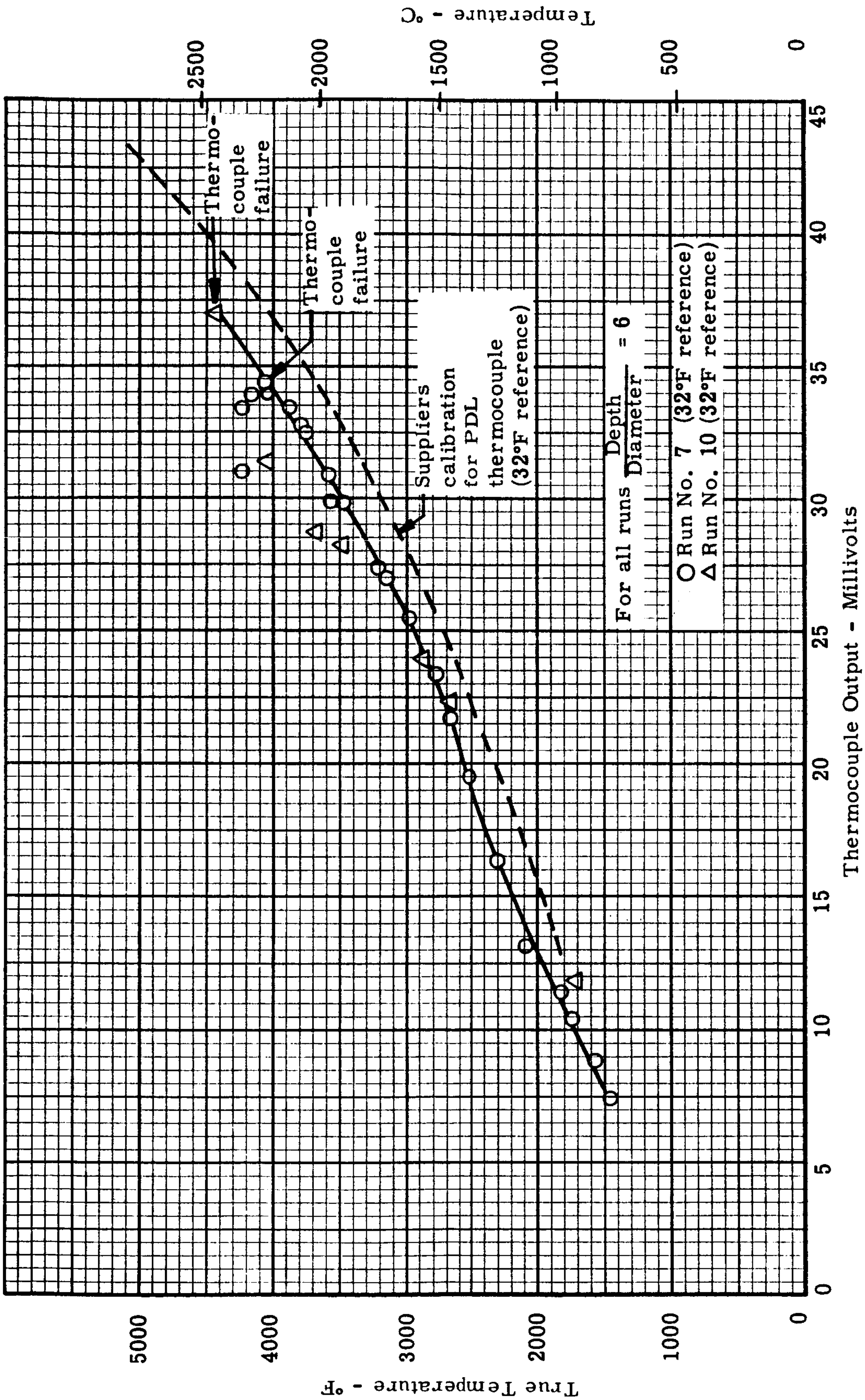

Figure 4. Final Calibration Curves for PDL Thermocouple Against Black Body Cavity

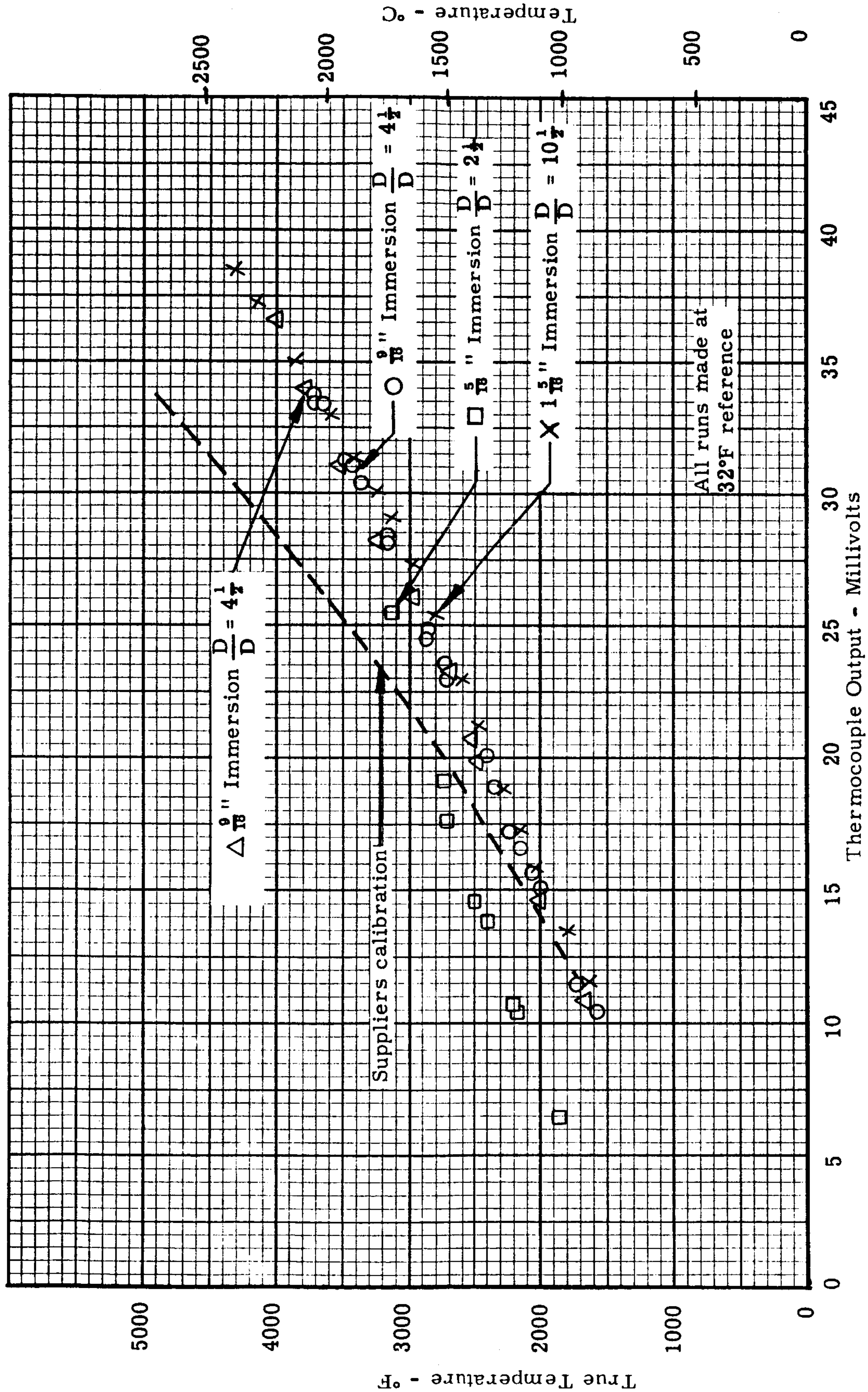

Figure 5. Variation of Thermocouple Output With Immersion Depth In Black Body Cavity for Fenwal Thermocouple

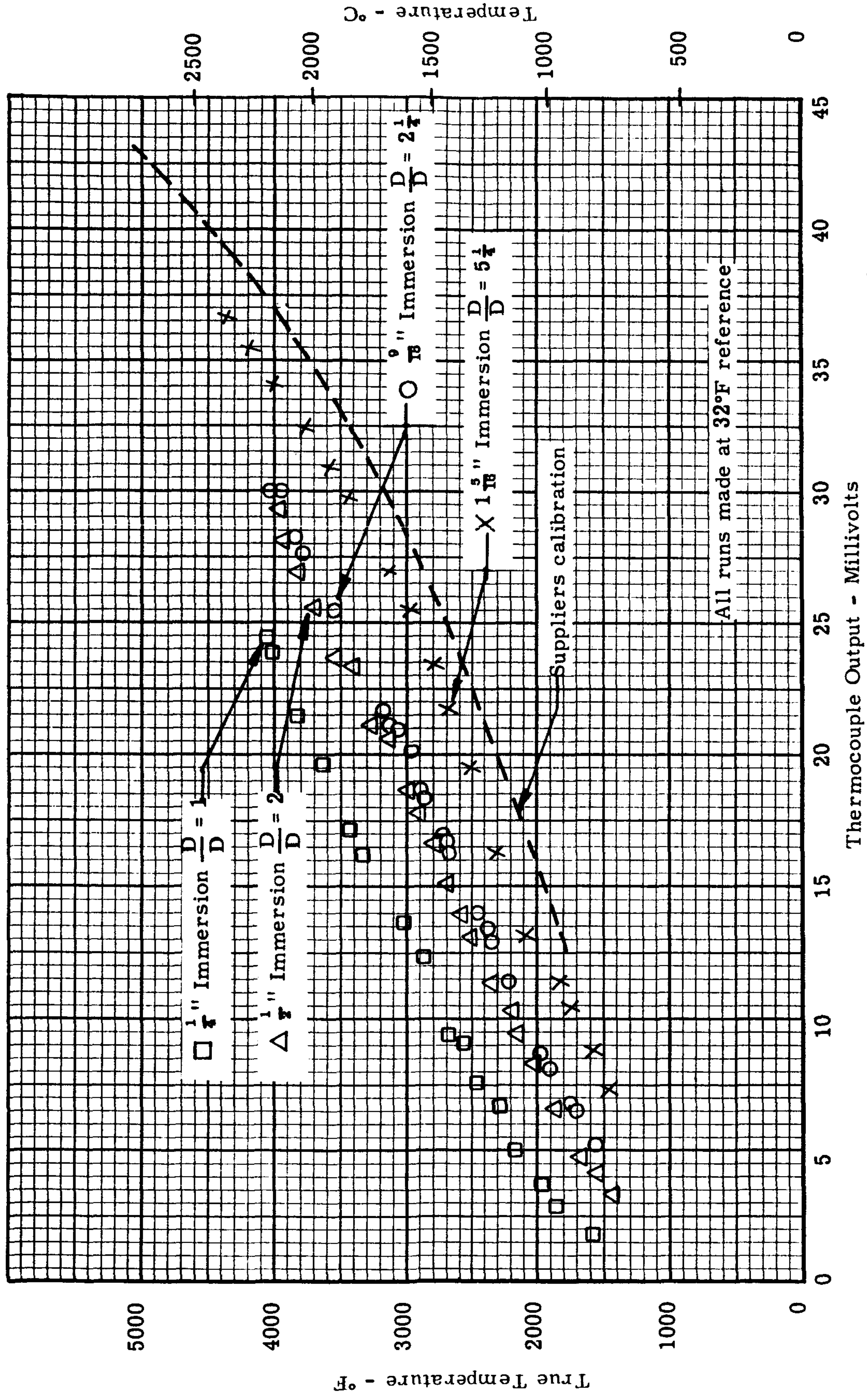

Figure 6. Variation of Thermocouple Output With Immersion Depth in Black Body Cavity for PDL Thermocouple

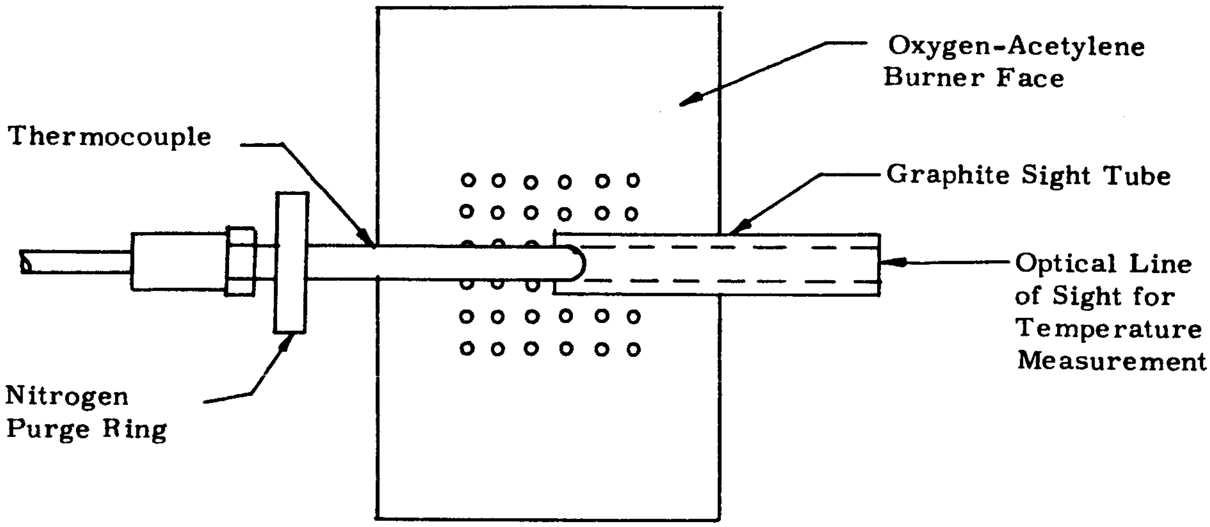

Figure 7. Schematic of Apparatus Utilized for Oxidizing Atmosphere Evaluations

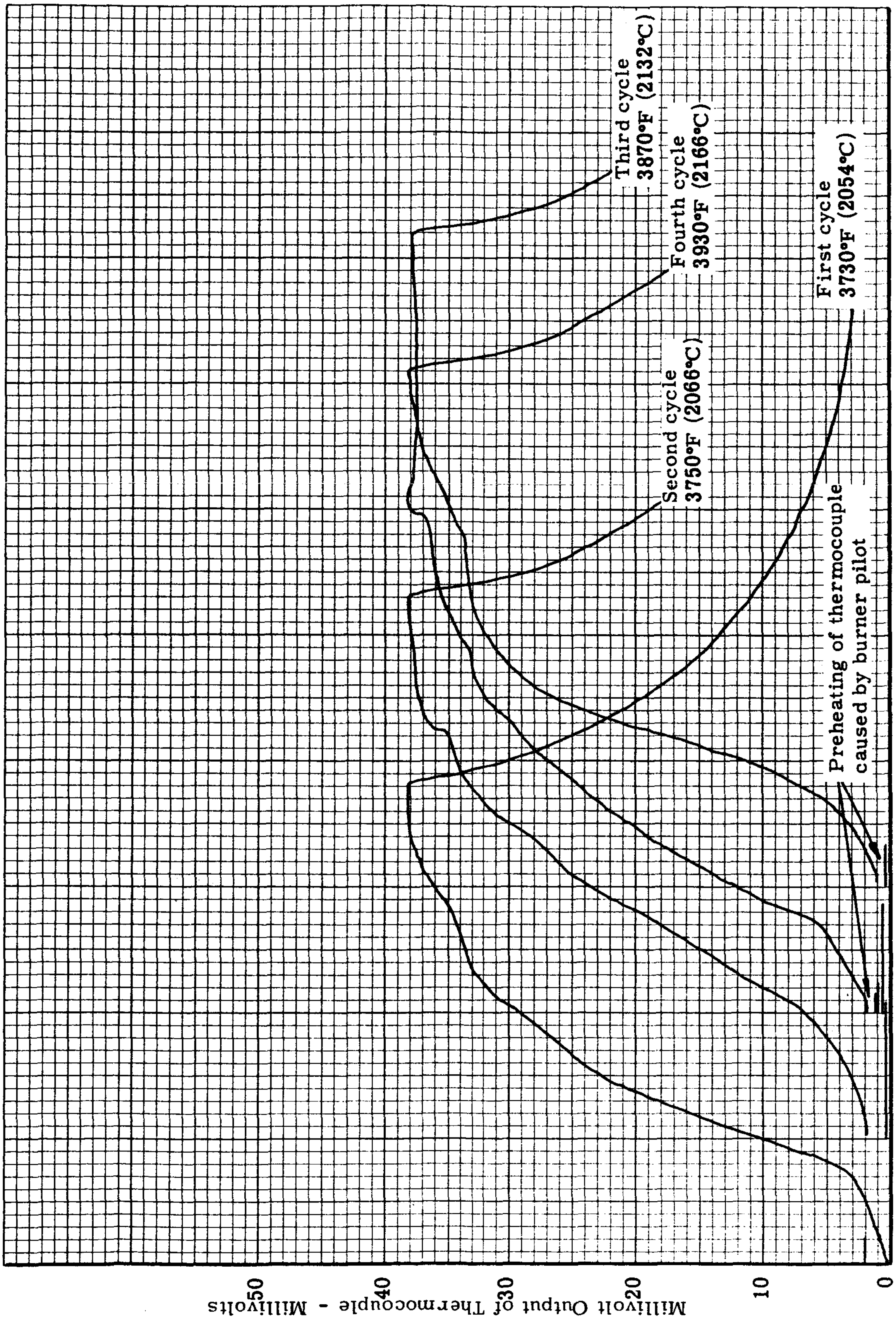

Figure 8. Millivolt Output versus Time Plot for a PDL Thermocouple Cycled to Approximately 2100°C

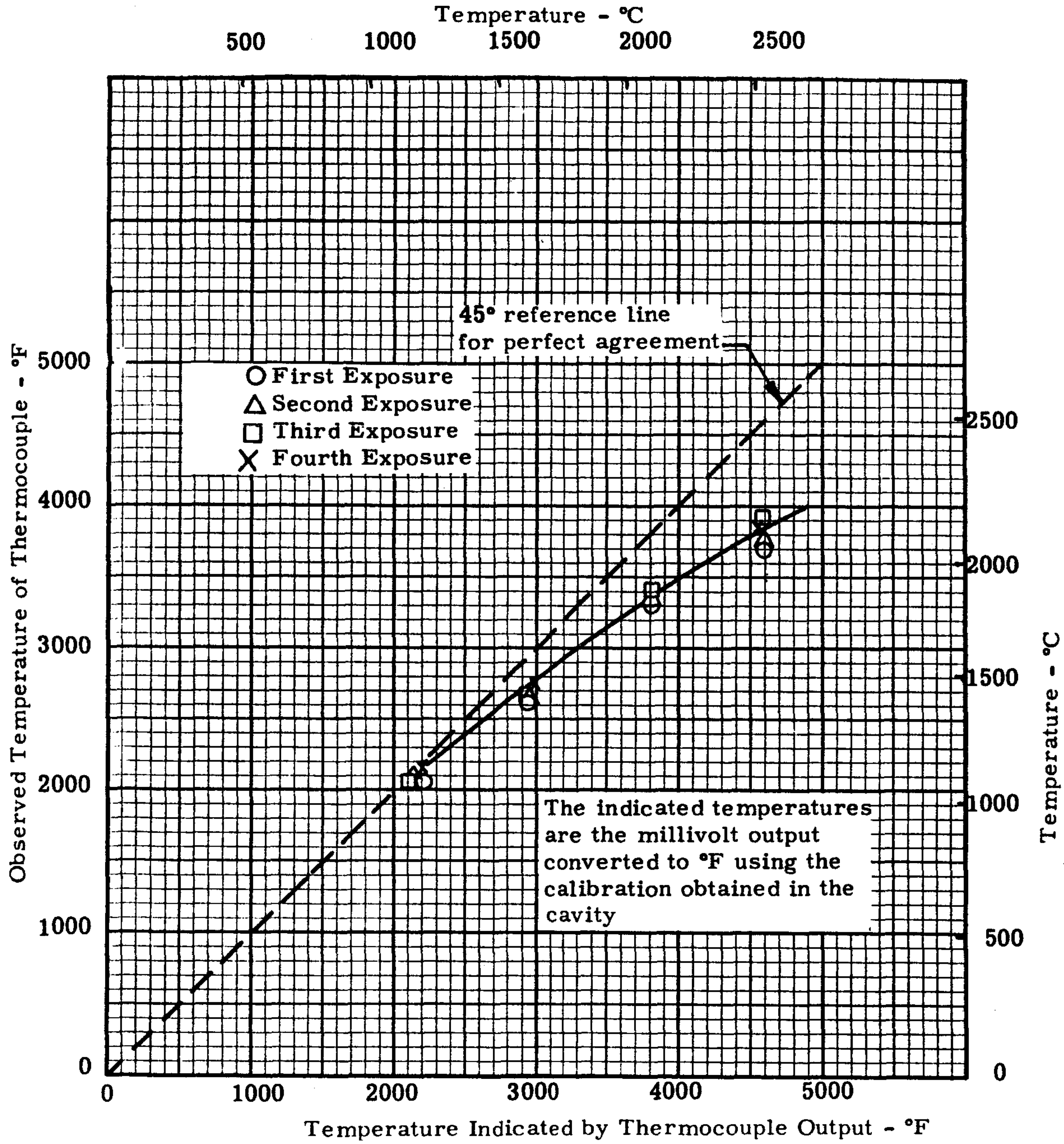

Figure 9. Comparison of Observed Temperature and Indicated Temperature for PDL Thermocouple in Burner Exposure

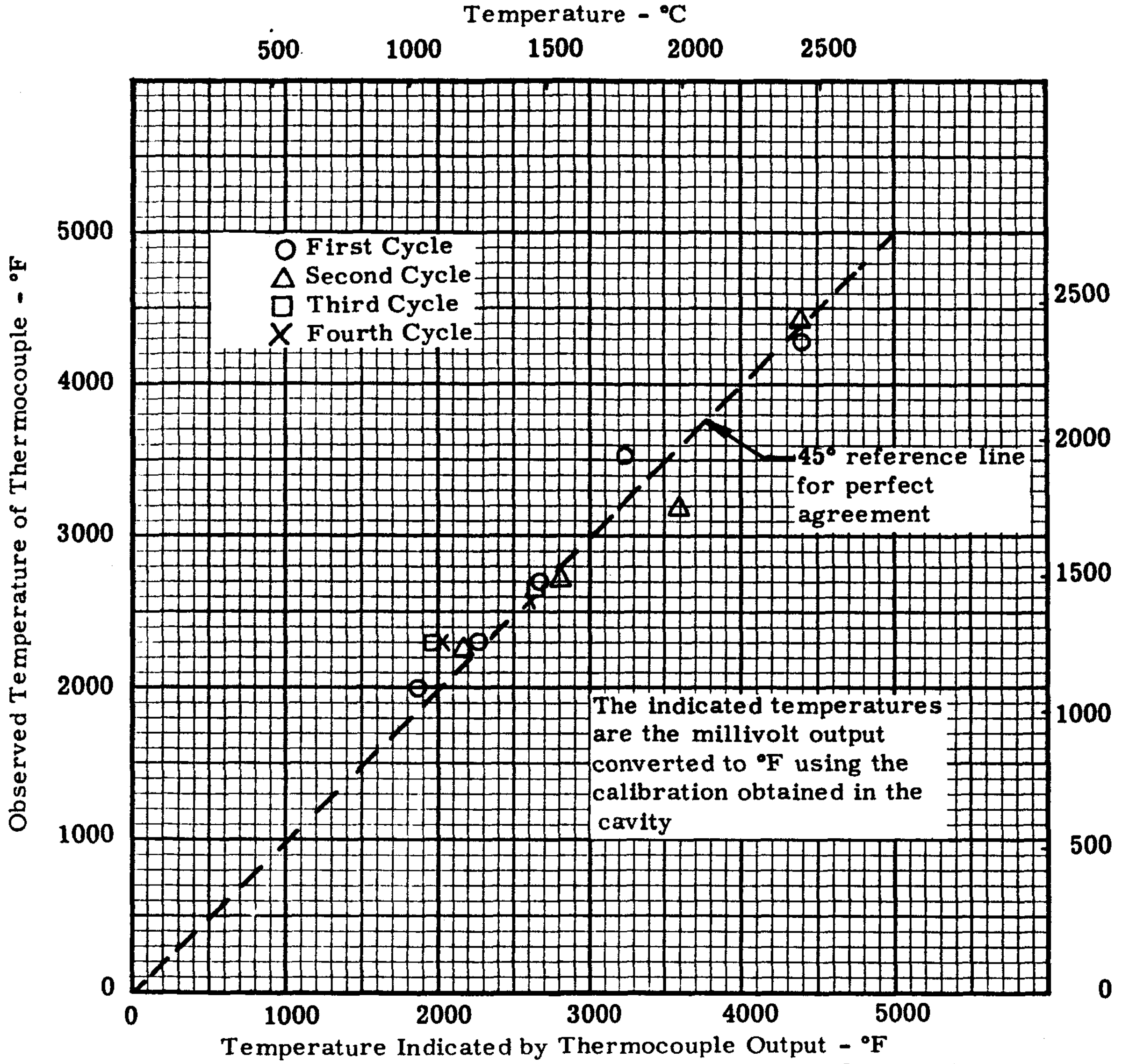

Figure 10. Comparison of Observed Temperature and Indicated Temperature for Fenwal Thermocouple in Burner Exposure

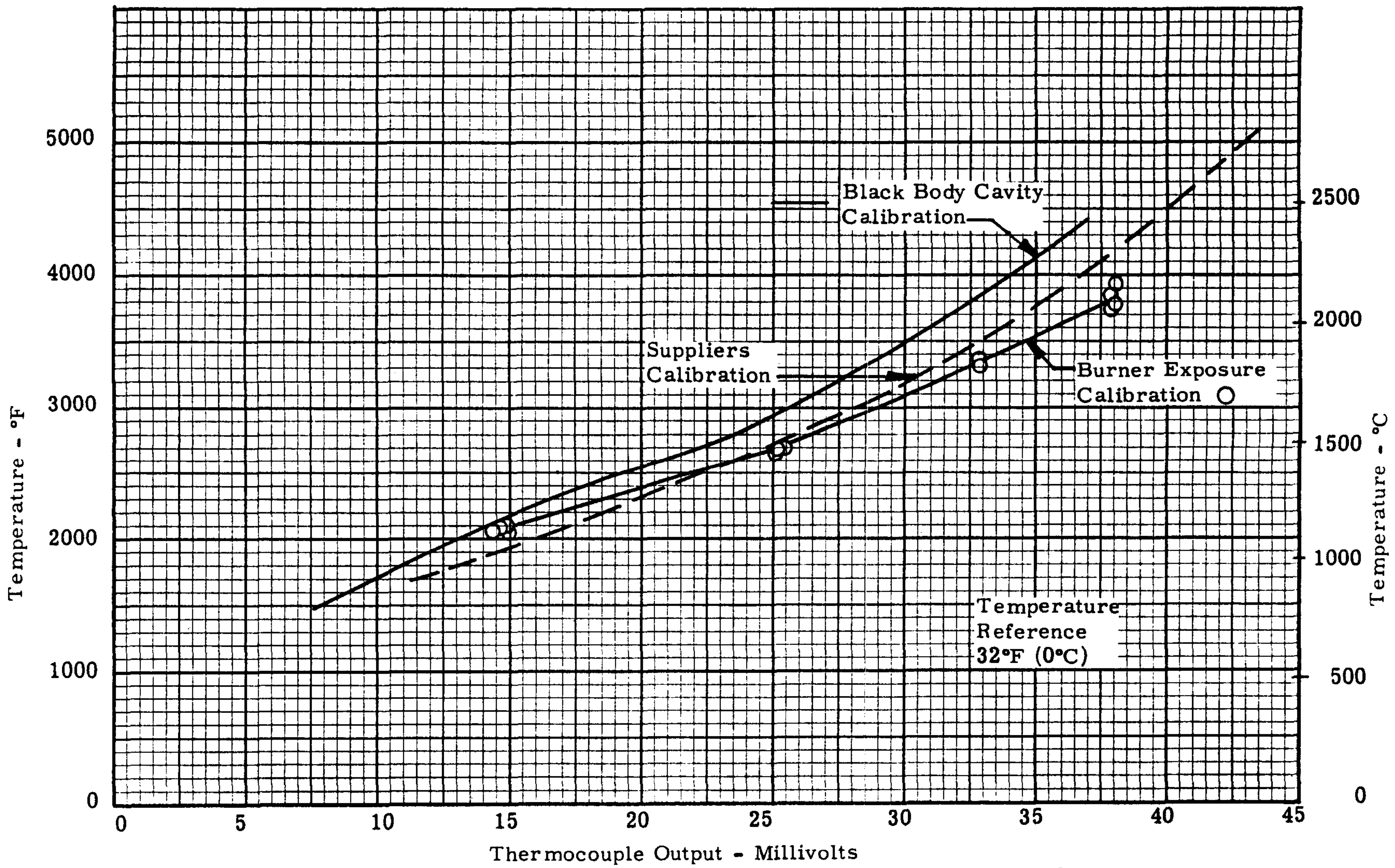

Figure 11. Comparison of Calibrations in Black Body Cavity and Burner Exposures for PDL Thermocouple

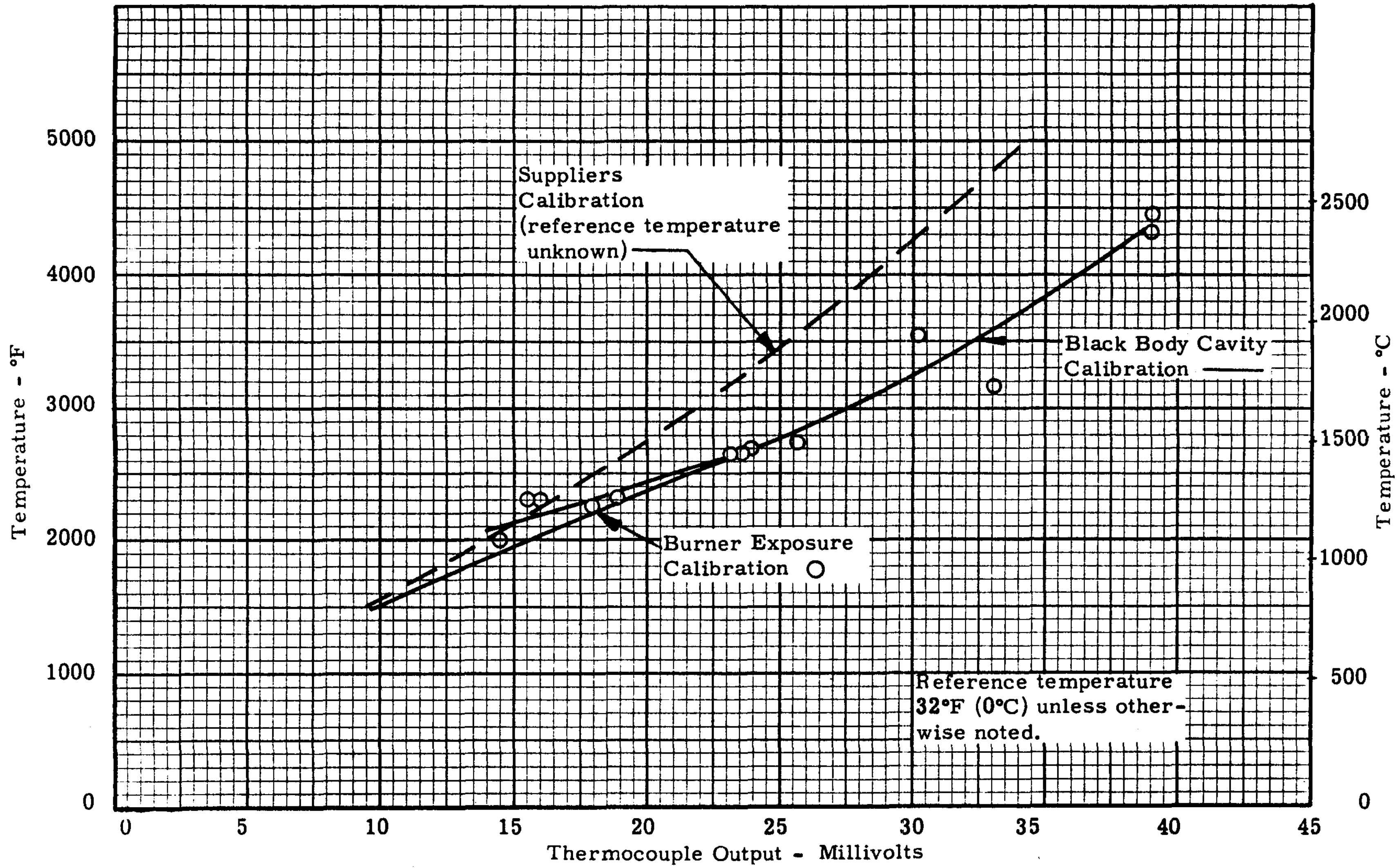

Figure 12. Comparison of Calibrations in Black Body Cavity and Burner Exposures for Fenwal Thermocouple

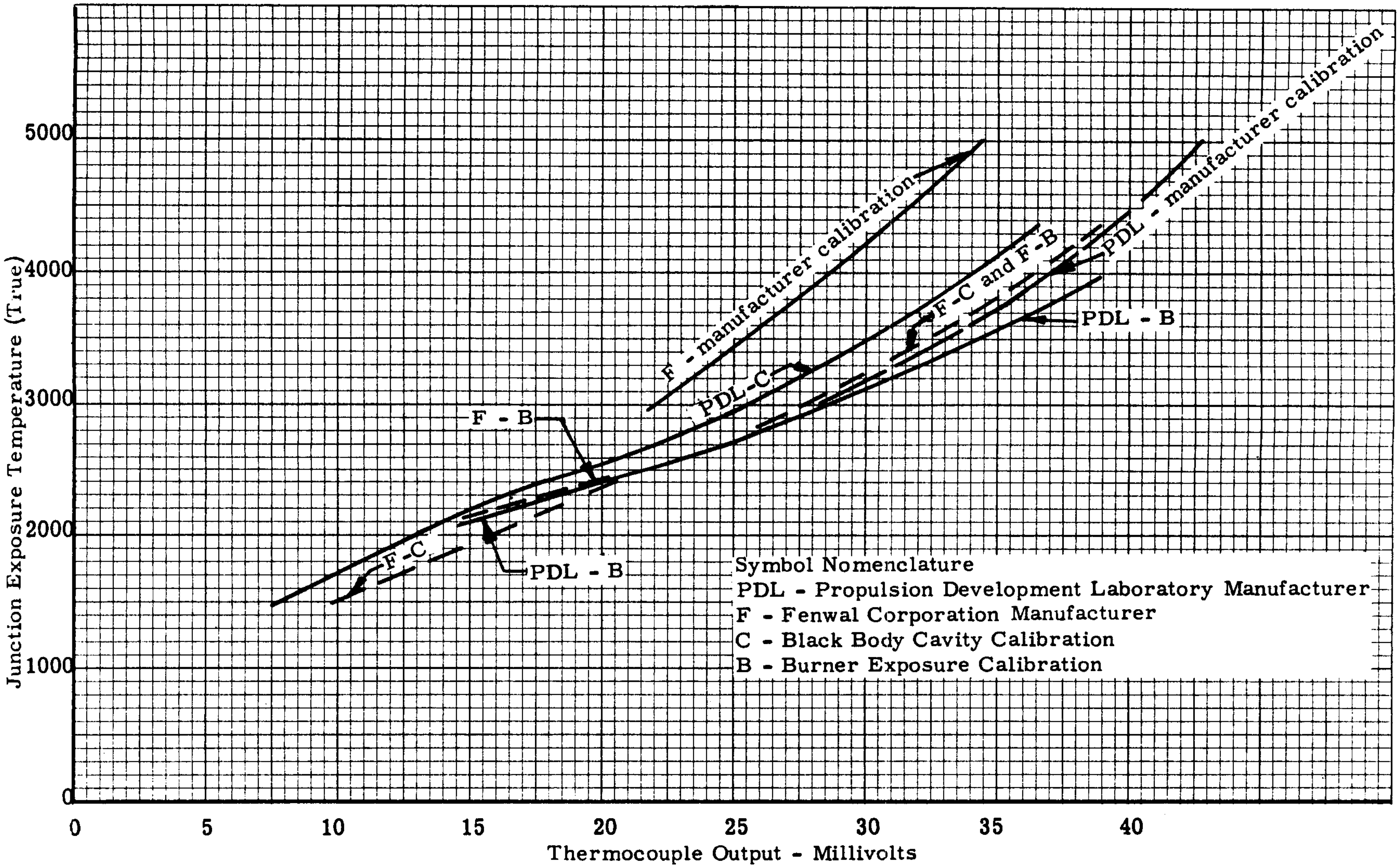

Figure 13. Comparison of Black Body Cavity and Burner Exposures for Fenwal and PDL Thermocouples

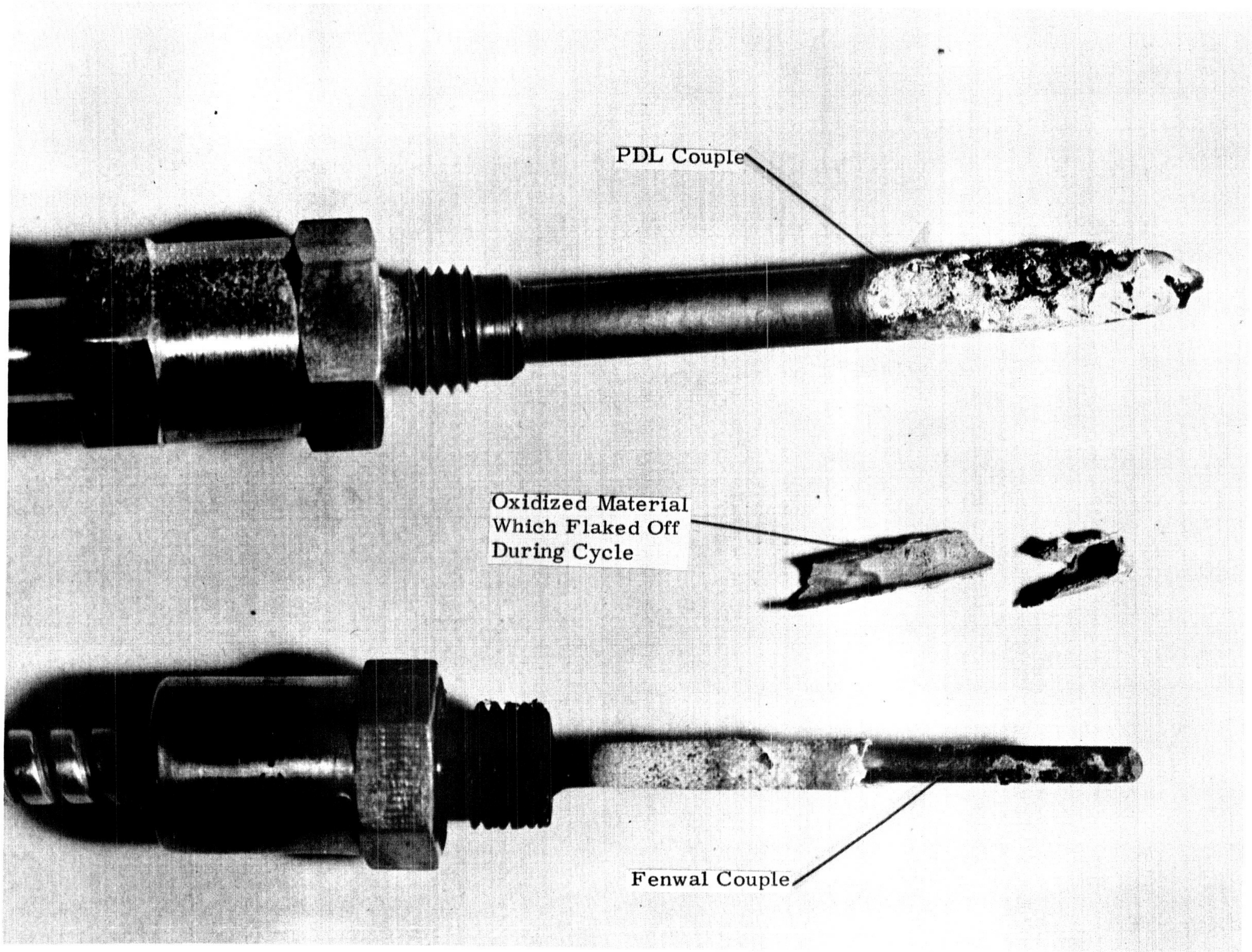

Figure 14. Picture of PDL And Fenwal Thermocouples After Exposures in Flame of Oxygen-Acetylene Burner

Table 1

Black Body Cavity Calibration of Fenwal Thermocouple

SRI Run Number	Time	Millivolt Output[1]	True Temperature °F	Remarks
Run No. 8	3:45	9.32	1445	
T.C. No.	3:46	10.05	1510	
5727-11-5	3:46	11.48	1625	
Immersion	3:51	11.87	1660	
Depth $10\frac{1}{2}$	3:53	15.29	1980	
diameters	3:55	17.10	2140	
	3:57	19.35	2350	
	3:59	20.16	2400	
	4:02	22.83	2540	
	4:04	23.75	2670	
	4:06	25.25	2780	
	4:07	25.82	2830	
	4:09	28.49	3055	
	4:10	29.04	3100	
Run No. 9	8:40	9.82	1420	
T.C. No.	8:42	10.78	1500	
5727-11-5	8:43	13.41	1770	
Immersion	8:45	14.40	1920	
Depth $10\frac{1}{2}$	8:47	19.00	2225	
diameters	8:48	19.54	2295	
	8:50	22.02	2505	
	8:52	22.71	2550	
	8:56	25.43	2820	
	9:01	27.34	3005	
	9:03	28.90	3155	
	9:05	29.97	3250	
	9:07	31.34	3430	
	9:09	31.92	3500	
	9:11	33.09	3635	
	9:12	33.24	3635	
	9:14	34.72	3820	
	9:16	34.85	3900	
	9:17	36.19	4030	
	9:19	36.40	4065	

Table 1 Continued

Black Body Cavity Calibration of Fenwal Thermocouple

SRI Run Number	Time	Millivolt Output[1]	True Temperature °F	Remarks
Run No. 9	9:21	37.86	4265	
T.C. No.	9:22	38.20	4310	
5727-11-5	9:23	38.40	4430	
Immersion	9:24	38.30	4395	
Depth $10\frac{1}{2}$ diameters	9:26	32.46	3580	This point obtained during cooling
Run No. 11	4:15	10.32	1510	
T.C. No.	4:17	19.42	2250	
5727-11-5	4:19	27.45	2980	
Immersion	4:20	34.55	3675	
Depth 11	4:21	38.39	4035	
Diameters	4:22	38.83	4370	
	4:23	36.05	4610	Thermocouple failed. millivolt output decreased to zero

[1] Reference temperature 32°F (0°C)

Table 2

Black Body Cavity Calibration of PDL Thermocouple

SRI Run Number	Time	Millivolt Output[1]	True Temperature °F	Remarks
Run No. 7	10:26	7.27	1460	
T.C. No.	10:29	8.76	1580	
PN 4737	10:31	10.40	1730	
P_SN 007	10:32	11.35	1815	
Immersion	10:37	13.31	2050	
Depth $5\frac{1}{4}$	10:40	16.25	2300	
diameters	10:42	19.45	2500	
	10:44	21.71	2675	
	10:45	23.44	2775	
	10:47	25.50	2990	
	10:49	26.98	3135	
	10:51	27.29	3225	
	10:53	29.84	3475	
	10:57	29.75	3550	
	10:58	30.80	3580	
	11:00	32.48	3750	
	11:01	32.59	3770	
	11:08	34.27	4050	
	11:10	34.10	4050	
	11:15	33.87	4180	
	11:17	33.33	4220	Millivolt output began decreasing
	11:19	31.00	4220	Millivolt output decreased to zero
Run No. 10	1:41	11.79	1705	
T.C. No	1:45	22.31	2680	
PN 4734	1:46	23.80	2890	
SN 013	1:48	28.16	3500	
Immersion	1:50	28.45	3700	
Depth 6	1:51	31.25	4060	
diameters	1:52	27.00	4450	Thermocouple failed. Millivolt output decreased to zero

[1] Reference temperature 32°F (0°C)

Table 3

Millivolt Output at Various Temperatures for PDL Thermocouple as Found During Exposures in Burner Environment

Series Number	Cycle Number	Observed Temperature °F	Millivolt Output mu	Indicated Temperature Determined from Cavity Calibration °F
1	1	2065	15.0	2190
	2	2090	14.8	2080
	3	2085	14.4	2065
	4	2110	14.9	2185
2	1	2650	25.1	2940
	2	2685	25.2	2950
	3	2700	25.4	2990
	4	2695	25.2	2950
3	1	3350	32.8	3830
	2	3350	32.8	3830
	3	3390	32.8	3830
4	1	3730	38.1	4610[1]
	2	3750	38.1	4610[1]
	3	3870	37.8	4580[1]
	4	3930	38.0	4600[1]

[1] Temperatures read from extrapolated calibration curves.

Table 4

Millivolt Output at Various Temperatures for Fenwal Thermocouple As Found During Exposures in Burner Environment

Series Number	Cycle Number	Observed Temperature °F	Millivolt Output mu	Indicated Temperature Determined from Cavity Calibration °F
1	1	2000	14.4	1890
	2	2325	18.8	2280
	3	2280	17.8	2190
	4	2300	15.5	1990
	5	2300	16.0	2010
2	1	2700	23.9	2690
	2	2730	25.7	2810
	3	2660	23.6	2650
	4	2660	23.1	2610
3	1	3530	30.1	3250
	2	3170	33.0	3600
4	1	4300	39.0	4390
	2[1]	4440	39.0	4390

[1] Approximately 50% of thermocouple cylinder oxidized during exposures broke away from uncontaminated substrate.